Fitting The Workplace To The Human And Not Vice Versa

By K. H. E. Kroemer
Virginia Tech

The human is the most important component of a system since she or he drives the output. Hence, the human must be accommodated first: the design of the workplace components should fit all operators and allow many idiosyncratic variations in working posture. The myth of "one healthy upright posture, good for everybody, anytime" must be abolished.

Healthy sitting

In 1884, Staffel published his theories about "proper" sitting postures and deduced from these recommendations for seat and furniture design. His opinion was that "sitting with an upright trunk means sitting healthily," which was based on the concept that the spinal column of the sitting person should be "erect" or "upright" (a contradiction in terms because it is actually curved, in the side view) similar to that of a "healthy normal upright standing" person. Special emphasis was placed on maintaining a "normal" lumbar lordosis. This posture was believed to put the least strain on the spinal column and its supportive structures, including the musculature, and it was considered "socially proper." Recommendations for the design and use of seats were based on this desired posture. These ideas about suitable posture and furniture were repeated in the literature, apparently without much questioning or contradiction, until the middle of this century.

EFFECT OF BACKREST

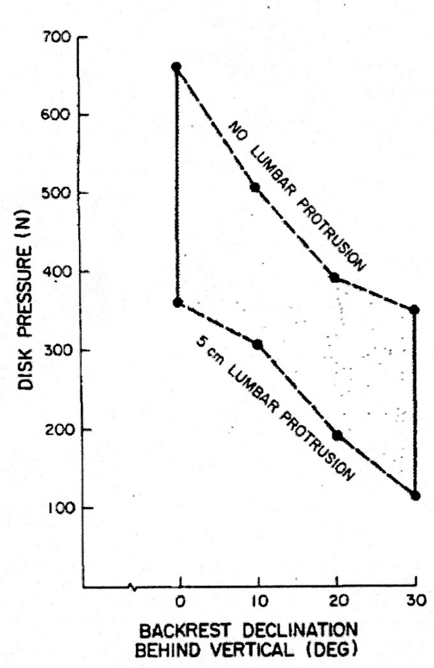

Figure 1

Each vertebra rests upon its lower one cushioned by the spinal disk between their main bodies, and also supported lateral-posteriorly in the two facet joints of the articulation processes. Since the downward pull of vertical trunk muscles generates disk and facet joint strain (in response to upper body weight and external forces) one should expect close relationships between trunk muscle activities and disk pressures. In the 1960s, experiments were performed in Scandinavia where pressure transducers were placed into spinal disks. These experiments showed that the amount of intra-disk force in the lumbar region was dependent upon trunk posture and support.

When standing at ease, the forces in the lumbar spine are in the neighborhood of 330 newton (N). This force increases by about 100 N when sitting on a stool without backrest. It makes little difference if one sits erect with the arms hanging, or relaxed with the lower arms on the thighs. Thus, there is an increase in spinal compression force in the lumbar region when sitting down from standing; but the differences among sitting postures are not very pronounced. About the same force values were found when sitting on an office chair with a small lumbar support. Sitting with the arms hanging, writing with the arms supported on the table and activating a pedal lead to forces around 500 N. The spinal forces are increased by typing, when the forearms and hands must be lifted to keyboard height. (A further increase is seen when a weight was lifted in the hands with forward extended arms.) None of these postures make use of the backrest. However, if one leans back decidedly over a small backrest, and lets the arms hang down, the internal compression forces are reduced to approximately 400 N.

Figure 1 shows the effect of backrest use even more dramatically. When the backrest is upright, it cannot support the body, and disk forces between about 350 and 660 N may occur.

Declining the straight backrest behind vertical brings about dramatic decreases in internal force, because part of the upper body weight is now transmitted to the backrest and hence does not rest on the spinal column. An even more pronounced effect can be brought about by making the backrest protrude towards the lumbar lordosis. A protrusion of five centimeters nearly halves the internal disk forces from the values associated with the flat backrest; protrusions of four to one centimeters in the lumbar region bring about proportionally smaller effects.

In a series of more recent studies, disk pressures were measured and calculated for various desk tasks and for sitting and standing postures. One of the conclusions was: "In a well-designed chair the disk pressure is lower than when standing." If the backrest consists only of a small lumbar board, a dramatic beneficial effect requires that one nearly "drapes oneself on it" by leaning backwards over it. Even a large backrest that can support

the total trunk is nearly useless when upright, but highly beneficial when declined backward behind vertical. Its positive effects are dramatically enhanced if it is shaped to bring about the S-curve of the spinal column, particularly the lumbar lordosis.

Relaxed leaning against a declined backrest is the least stressful sitting posture. This is a condition that is often freely chosen by persons working in the office if there is a suitable backrest available: "...an impression which many observers have already perceived when visiting offices or workshops with VDT workstations: Most of the operators do not maintain an upright trunk posture.... In fact, the great majority of the operators lean backwards even if the chairs are not suitable for such a posture."

Free posturing

Currently, no one simple theory about the proper, healthy, comfortable, efficient sitting posture at work prevails. With the idea abolished that everybody should sit upright, and that furniture should be designed to this end, the general tenet is that many postures may be comfortable depending on one's body, preferences and work activities. Consequently, it is now generally presumed that furniture should allow many posture variations and permit easy adjustments in its main features, such as seat height and angle, backrest position, or knee pads and footrests; and that the computer workstation should also allow easy variations in the location of the input devices and of the display. Thus, change, variation and adjustment to fit the individual appear central to well-being. If any label can be applied to current theories about proper sitting, it may be "free posturing."

The free posturing design principle has these basic ideas:

- Allow the operator to freely assume a variety of sitting (or standing) postures, make workstation adjustments, and even to get up and move about;
- Design for a variety of user dimensions and for a variety of user preferences; and
- New technologies develop quickly and should be usable at the workstation. (For example, radically new keyboards and input devices including voice recognition may be available soon; display technologies and display placement are undergoing rapid changes.)

The office workstation

Successful ergonomic design of the workstation in the office depends on proper consideration of several interrelated aspects (Figure 2). The work task, the work posture, and the work activities all interact, and are influenced by the workstation conditions including furniture and other equipment, and by the environment. All of these must fit the person. Work postures determine to a large extent the person's well-being, and work activities, of course, determine the work output. Naturally, the person's well-being also influences performance, and many people feel good if they are satisfied with their performance. Thus, there are many interactions in the relations among person, task, conditions and results of the effort.

INTERRELATED ASPECTS OF THE WORKSTATION

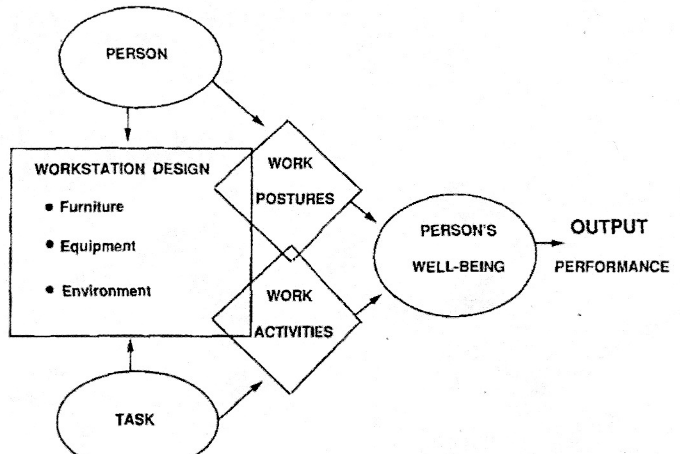

Figure 2

There are several links between a person and the job. The first is the visual interface: one must look at the written material, the keyboard, the computer screen and/or the printed output. The second is manipulation: the hands operate keys, a mouse or other input devices such as pen, paper and telephone. The intensity of the visual and motor requirements depend on the specific job. A third link may exist between the feet and controls operated with them, such as when starting and stopping a dictation machine. Finally, the body and the seat (if one is used) are linked at the undersides of the thighs and buttocks, and at the back when a backrest is used. These four interface areas all have major impacts on the proper design of the office workstation and its components.

The visual interface

In conventional "paper" offices, the text to be read is usually placed on the regular working surface, roughly at elbow height. If an object needs to be looked at more closely, it is lifted to a proper relation to the eyes. An inclined surface for easier reading has been recommended often to make its angle with the line of sight closer to 90 degrees. The disadvantage of the inclined work surfaces is materials sliding or rolling. Therefore, there is usually only a flat surface available, on which the various objects are placed at will.

If a typewriter is used, there are several visual targets. One is the printing area, the platen on a conventional typewriter, the display area on electronic typewriters. This is usually located somewhat above the height of the keyboard, and located fairly well with respect to human vision capabilities and preferences, although its display surface is very small. A problem has been, in many cases, the placement of a source document from which text is copied. To place it horizontally on a horizontal surface is quite often uncomfortable and makes exact reading difficult. Therefore, various types of document holders have been used that put the source document more vertical and closer to the eyes. Still, often this document holder is placed far to one side, requiring a twisted body posture and lateral head and eye movements.

Proper placement of all visual targets is often a problem. First, with the large increase in the number of keys on most computer keyboards, many operators scan the keys again, while previously typists were able to do their job without looking at the keys. Thus, the computer keyboard is a rather large, nearly horizontal visual target area, usually placed on the work surface. Second, there is the display area of the computer monitor (the screen), commonly placed in front of the operator or at about right angles to the line of sight. Third, there is often some sort of source document from which information must be gleaned. Its placement causes problems like those encountered by typists, but in some cases that source document is fairly large, such as a drawing used in computer-aided design.

The placement problem is partly one of available space within the center of the

KEYBOARD DEVELOPMENTS

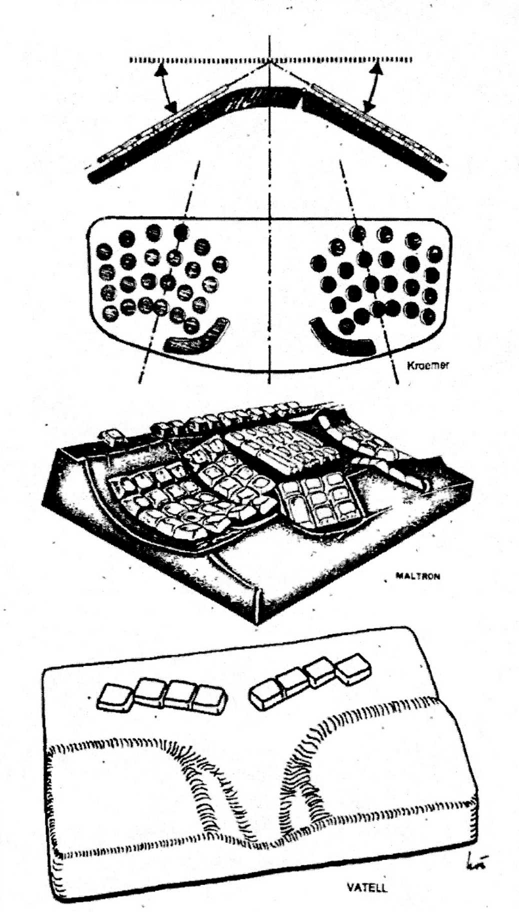

Figure 3

person's field of view. Research has shown that people in a conventional sitting posture prefer to look downward at angles between 10 and 40 degrees below the horizon instead of looking straight ahead as falsely assumed in some military design guidelines. They do so by inclining the head forward and by rotating the eyeballs downward, instead of looking straight ahead. This appears to be a natural way of focusing at a near target with least effort; the more upwards one has to tilt one's eyes, the more difficult it becomes to focus. Thus, putting the monitor up high behind the keyboard (often by placing it on the CPU box of the computer or on a so-called monitor stand) is rather uncom- 'iewer. Instead of build- ver, the screen should be tely behind the keyboard, ge as near as possible to f the keyboard. A printer may be placed above the monitor, and a source document be placed next to them. More refined solutions may incorporate all three visual areas in one setup.

One speaks of indirect glare at the computer workstation if a light source is reflected from the screen surface, like a window or a lamp or a white shirt are reflected in a mirror. The reflected bright spot or surface on the screen interferes with the attempt of the eyes to see the displayed characters or drawings. The contrast between the character and its background is often so much reduced by the reflection that extraordinary efforts must be made by the eye to discern differences. This can lead to eye fatigue, a rather undefined but descriptive and popular term. A similar irritating condition may be generated if an intensive light source (the sun, light coming in from a window, or a bright lamp) shines directly into the eyes of the computer operator, thus generating high illumination of the retina where rods and cones are trying to discern comparatively light contrasts between characters and their background on the screen. Having understood the nature of the problem makes means to avoid it self-evident: one must move the sources of indirect or direct glare away from the operator's eyes. This can be done in several ways: one is to move the screen (that acts like a mirror) so that the rays coming from the light sources are not reflected into the human eyes. However, instead of moving the screen, one might move the light sources, such as task lights, or one may dim the sources, such as pulling a curtain over the window or putting a louver over a ceiling light. Dimming the light source is the obvious solution if the operator (and the monitor) can not be placed differently. The operator might refrain from wearing a white or light colored shirt or blouse. The reflection of glare sources is less on screens with light background — and dark characters — than on screens with dark background (which act like mirrors).

The removal of the disturbing light source from the field of vision, is, of course, the basic solution. Changing the reflections in the monitor screen is the second-best solution. One might either turn the screen, turn the operator, or put devices on the screen to avoid reflections. These might be hoods that do not allow a light source to be beamed onto the surface, or one may resort to anti-reflection coating of the surface, or to filters, of which there are several kinds available. While some of these may improve the conditions, this is not done without penalty: coatings and filters reduce the intensity of passing light waves, thus diminishing the overall energy reaching the operator's eyes while improving contrast; others let light pass through only in certain directions, thus restricting the possible location of the eyes. Therefore, it is better to remove the source of the problem rather than trying to influence the transmission path.

Eye lenses

Computer operators often find that they must wear corrective lenses, particularly spectacles. But to use corrective lenses incorrectly can generate new problems. This is particularly often the case with so-called reading glasses. These are ground for a viewing distance of about 40 to 50 centimeters and for a downward tilt of the line of sight of approximately 25 degrees, but many visual targets in the computer area are placed further away, particularly the screen which is commonly behind the keyboard. If the visual target is beyond the focusing distance, one is tempted to squint the eyes while trying to focus, or to move the head forward to bring it closer to the correct focusing distance. The first attempt may lead to eye fatigue, the second to improper neck posture and muscle tension. This is even more pronounced if one wears bifocals or tri-focals, where the lowest section is meant for reading. In this case, one is likely to tilt the head backwards in order to get the display on the screen on the line of sight, which is predetermined by the glasses to be downward, with respect to the head. Ensuing severe tilting of the head often gives rise to muscular tension and severe headaches. The solution is to wear full-size corrective lenses ground for the correct viewing distance, even if this blurs the impression of objects further away. Musicians, for example, habitually have their glasses ground to a distance of about one meter so that they can focus on their sheet music.

The motoric interface

Unfortunately, the traditional typewriter keyboard is still used, largely unchanged except that it may have more than 100 keys, as the major input device for computers. The conventional keyboard has several un-ergonomic features, such as letters that frequently follow each other in English text (such as q and u) are spaced apart on the keyboard. This was originally done so that mechanical type bars might not entangle if struck in rapid sequence. Another characteristic is that the columns of keys run diagonally from left to right, which was also necessary on early typewriters due to the mechanical constraints of the type bars. Yet, the keys are arranged in straight sideways rows, which the fingertips are not. The keyboard must be

operated with the hands pronated (thumbs down), due to the horizontal arrangement of the rows of keys. Furthermore, there is a large number of keys of which one must be correctly selected so that the desired character can be produced. This requires, cognitively, that a difficult multi-choice decision must be made, followed by motorically complex use of muscles to move the finger to the proper key.

ADJUSTMENT RANGES FOR VDT WORKSTATION HEIGHTS (cm)	
Seat Pan	37 (15) to 51 (20)
Keyboard Support	51 (20) to 70 (28)
Screen Center	75 (30) to 130 (51)
Work Surface	51 (20) to 70 (28)

Table 1

Mechanical keyboards had strong key resistances and required large key displacement. Hence, it was suspected that weak fingers, particularly the little ones, were overworked. Thus, many recommendations for improvements of the traditional keyboard have been proposed in the past: they included relocation of the letters on the keyboard and new geometries of the keyboard, such as curved arrangements of the keys. Also suggested was dividing the keyboard into one half for the left hand and one for the right hand, so arranged that the center sections are higher than the outside, thus avoiding the pronation of the hand required on the flat keyboard; and various proposals to use two keys simultaneously (chording) to generate one character. A new idea is to use chording in combination with keys that have three status conditions, i.e. ternary instead of the usually binary keys. The "ternary chord keyboard" requires only very few keys, such as one for each finger, to generate possibly thousands of different characters. Keyboard developments are shown in Figure 3.

Small keyboards can be placed nearly anywhere, at the user's convenience, such as on one's lap (which was quite difficult with the traditional large keyboard but was done by some operators nevertheless) or they may be incorporated in an arm rest, in a glove, or even in the shell of a space suit. New developments may radically change the nature and appearance of keyboards, and hence allow new body and hand postures.

The sitdown workstation

Among the first steps in designing office furniture for human use is to establish the main clearance and external dimensions; derived from the anthropometric data of office workers.

The results of the calculations (using data on U.S. civilians) are compiled for "conventional" furniture in Table 1. It contains the height adjustments necessary to fit about 90 percent of the civilian population by excluding only females who are smaller than the 5th percentile in the relevant dimension, and males who are larger than the 95th percentile. These dimensions will provide fit to nearly all computer users but do not assume or require certain postures, such as upright trunk or horizontal forearms; instead, either of these design solutions allows much freedom in sitting how one likes, from bending forward to leaning back, having the legs at will within the leg room provided.

To permit changes in hand/arm and eye locations as well, the input device (e.g. keyboard) should be movable within the work space. Also, one should be able to move the display screen to various heights which requires an easily adjustable or spring-motor driven suspension system of the support surface.

All components of the VDT workstation must fit each other, and each must suit the operator. This requires easy adjustability. Figure 4 sketches various adjustment features which allow matching the seat height with the height of support of the input devices or table, possibly while using a footrest; and to place the monitor on its support.

The stand-up workstation

Another way to change working posture is to allow the computer operator, at his or her own choosing, to work for some period of time while standing up. Such stand-up workstations can often use a spare computer in the office, to which work activities can be switched from the sit-down workstation for a while; or one may stand while reading, or writing or telephoning. Stand-up workstations should be adjustable to have the input device at approximately elbow height when standing, i.e., between 90 and 120 centimeters. As in the sit-down workstation, the display should be located close to the other visual targets, such as source document and keyboard. If the surface is used for reading or writing, it may be slightly declined. A footrest at about 2/3 knee height (approximately 30 centimeters) is often well liked so that the person can prop one foot up on it temporarily. This brings about changes in pelvis rotation and in spine curvature.

Ergonomics of computer work

The phantom of the average person sitting upright with right angles at elbows, hips and knees must be abolished and replaced by a design model that incorporates the actual range of body sizes and of working postures, and their large variations reflecting individual sitting and standing preferences.

Long-term work with computers, particularly if it consists of extensive periods of data entry, requires ergonomic measures to assure that the job is healthy, satisfying and productive. Several ways exist to achieve these goals. The first concerns the work environment and the work equipment. The second considers job content and work organization. The third utilizes technological progress to change the work altogether.

Environment

The work environment should be designed along the same guidelines that apply to any office work, but special attention is needed regarding the lighting, the furniture and the computer equipment used.

The illumination level at the computer workstation is lower than required in ordinary offices. The reasons are to avoid reflections on the screen (glare), and the fact that the screen is itself a source of light, which must be frequently viewed by the operator. Therefore, the general room illumination should be between 300 and 700 lx, with the lower levels appropriate when hard copy used (paper source document) is of high quality (good contrast). If difficulties in reading the source document exist at low level illumination, a task lamp may be used that shines exclusively upon the copy. The distribution of the illumination should be fairly constant throughout (with the exception of the spotlighted area), and be either diffuse or so directed that reflections on the screen are diligently avoided. Wall and ceiling colors are a matter of light reflectance and of personal preferences and have (against popular belief) no direct effect on mood or work output.

Noise is usually not a major concern since most computers operate at fairly low sound levels. However, a cooling fan or transformer may need attention. Background noise, and noise interfering from other workstations or equipment need to be considered. Altogether, the general recommendation is to keep the sound levels as low as possible, such as 60 dBA.

Seat Pan: The surface of the seat pan must support the weight of the upper body comfortably and securely. Hard surfaces generate pressure points, which can be avoided with suitable upholstery, cushions or by providing other surfaces that can elastically/plastically adjust to body contours.

"The only inherent limitation to the size of the seat pan is that it should be so short that the front edge does not press into the sensitive tissues near the knee. The height of the seat pan must be widely adjustable, best down to 38 centimeters (15 inches) and up to at least 50 centimeters (20 inches), better 58 centimeters (23 inches) to accommodate persons with short and long lower legs. This adjustment must be easily accomplished while sitting on the chair.

Usually, the seat pan is essentially flat, between 38 and 42 centimeters (15 and 17 inches) deep, and at least 45 centimeters (18 inches) wide. A well rounded front edge is mandatory. Often, the side and rear borders of the seat pan are slightly higher than the central parts of the surface, usually achieved by more compressibility of the inner sections.

In the side view, the seat pan is often essentially horizontal, but tilting it slightly (about five degrees) backward or forward is usually perceived as comfortable and desirable. Seat pans that are higher in their rear portion and lower at the front facilitate opening the hip angle.

Backrests: Backrests serve two purposes: to carry some of the weight of upper trunk, arms and head; and to allow muscle relaxation. Both purposes can be fulfilled only when the trunk reclines on the backrest.

The backrest should be as large as can be accommodated at the workplace. This means up to 85 centimeters (33 inches) high, and at least 30 centimeters (12 inches) wide. It should provide support from the head-neck on down to the lumbar region. For this purpose, it is in side view usually shaped to follow the back contours, specifically in the lumbar and the neck regions. An adjustable pad for the lumbar lordosis (e.g. an inflatable cushion) is appreciated by many users. The lumbar pad should be adjustable from 15 to 23 centimeters (6 to 9 inches), the cervical pad 50 to 70 centimeters (20 to 28 inches) above the seat surface.

The angulation of the backrest must be easily adjustable while seated. It should range from slightly behind upright (95 degrees) to 30 degrees behind vertical (120 degrees), with further declination for rest and relaxation desirable. Whether or not the seat back angle should be mechanically linked to the seat pan angle is a matter of personal preference.

Armrests: Armrests allows for support of the weight of hands, arms and even portions of the upper trunk and head. Thus, armrests are useful, though often used only for short periods of time. They must be well located and of suitable load-bearing surface. Adjustability in height, width, and possibly direction within rather small limitations may be desirable. However, armrests can also hinder moving the arm, pulling the seat up to a workstation, or getting in and out of the seat. In these cases, short armrests, or no armrest at all, is appropriate.

AJUSTMENT FEATURES OF A COMPUTER WORKSTATION

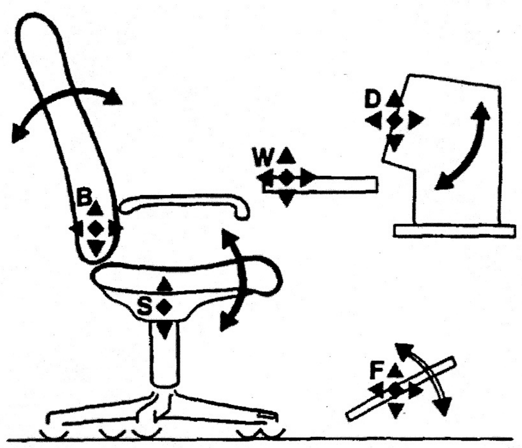

Figure 4

Footrests: A prevailing need for footrests usually indicates that the height adjustments, particularly of the seat pan, are not sufficient for the seated person. Hence, presence of footrests usually indicates deficient design.

If footrests are unavoidable, they should be so high that the sitting person has the thighs nearly horizontal. Footrests should not consist of a single bar or a small surface (because this severely limits the ability of the sitting person to change the posture of the legs); instead, the footrest should provide a support surface that is about as large as the total leg room available in the normal work position.

Job content

Most persons like to have autonomy in the performance of their work, to take responsibility for the quality and quantity of their work, and to control their timing. Most prefer to perform larger tasks from beginning to end instead of simply doing specialized tidbits. The ability to receive direct feedback about work performance, by reviewing one's own work daily, supplemented by constructive and positive comments from the supervisor, contributes essentially to the feeling of achievement and satisfaction. Within the limitations set by the requirement that certain work needs to be done, the operator should be free to distribute the workload, both in amount and in pace, according to one's own preferences and needs. Communication with colleagues and social relations are essential although at individually varying intensities. Isolating people or submitting them to cold formal relationships is usually detrimental to well-being and performance.

The organization of working time, particularly provision of changes in work and of taking rest pauses, is important for many computer tasks. Most people are bored by repetitive, monotonous, and continuous tasks; instead, varying tasks of different lengths should be provided so that the computer operator has occasion and cause to shift from one task to another, to move away from the computer for periods of time, to get or take away materials, do something else, or simply take a break. The recovery value of many short rest pauses is larger than that of a few long breaks.

Some of the current computer work tasks probably should not be imposed on humans, such as the long-time simple input of numbers or of word texts; not only because this is boring, but also because repetitive finger movements may be a source of cumulative trauma disorders such as tendonitis in hands or arms or carpal tunnel syndrome. Repetitive entry should be automated, e.g., by machine recognition of characters or voice. Feedback from the computer about its memory content can also be given to the operator through acoustical or sensory means other than just display on the screen.

Clever software offers possibilities to facilitate the task of the computer operator, such as automated programs for spelling, stringing of characters, algorithms that check and indicate outliers in data or unusual events or repetitive occurrences. Certainly, a wide variety of opportunities exist to change and, one hopes, to improve and facilitate the work of the computer operator.

K.H.E. Kroemer, Dr. Ing., is professor and director of the Industrial Ergonomics Research Laboratory at the Human Factors Engineering Center at Virginia Tech.

For further reading

For more information, including references, see the author's new book *Ergonomics*, in press by Prentice-Hall.